Galileo multispectral imaging of Europa: Evidence for non-synchronous rotation

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Visible and near-IR images of Europa's north polar region demonstrate that the color and albedo of fractures, triple-bands and other lineaments are correlated with their age, as determined from superposition relationships. Spectral mapping of these lineaments reveals a clockwise rotation of stress direction with time, consistent with faster-than-synchronous planetary rotation.

Multispectral imaging of Europa's northern high-latitude region was acquired at 37 degrees phase angle from a nontargeted flyby during Galileo's first orbit of Jupiter [1]. The imaged region extends across the trailing side of the antijovian hemisphere of Europa (longitudes 180 to 270), centered at 45°N, 221° W. 4-color coverage extends across the entire region, obtained with the violet, green, 756 and 968 nm filters, and an additional two filters were partially returned. False-color composites made up from these images show at least three distinct classes of linear features on Europa's surface. The most prominent linear features are the dark triple-bands such as Cadmus and Minos Linaea. The triple-bands cross-cut older lineaments (some with morphologies similar to triple-bands) which are brighter than the triple-bands, and intermediate in color between the triple-bands and the icy plains [2]. These older lineaments include a bright wedge at 60 N, 200 W, which is somewhat similar to the gray bands identified in the southern polar regions in Voyager images [3]. The youngest features appear to be incipient cracks, less than a pixel (1.6 km) wide, which cross-cut the triple bands.

These three classes of features apparently represent different stages of development of tectonic lineaments on Europa. Their distributions are shown in Figure 1, derived from photogeologic and spectral mapping (supervised classification) of the photometrically corrected 4-color data. Bands with spectral reflectance similar to the bright wedge (A) make up the stratigraphically oldest lineaments and generally have southwest-northeast trends. The intermediate-aged triple-bands (B) trend roughly east-west, with the younger of the two prominent criss-crossing bands near the center of the image (labeled “2”) having the more northwesterly trend. Rhadamanthys Linea (“R”), presumably a triple-band in the early stages of formation [1], has spectral characteristics similar to fully-developed triple bands but an orientation closer to that of the youngest fractures (C), which run northwest-southeast. The morphology of Rhadamanthys is transitional between the young fractures and the triple-bands, suggesting that these features are all formed by the same tectono-volcanic processes. If so, then a clockwise rotation of stress direction has taken place in this region over time.

Non-synchronous rotation may provide an explanation for the apparent changes in orientation of these lineaments. Calculations [4, 5] predict that Europa may rotate slightly faster than the synchronous rate, due to tidal torques caused by Europa's orbital eccentricity. As Europa's surface is reoriented relative to the tidal figure, the pattern of stresses experienced in the northern hemisphere should rotate in a clockwise sense, consistent with the observations. This is true both for tidal distortions [6] and for the stress fields induced by non-synchronous rotation [7, 8, 9]. Polar wandering (rotation about an axis through the sub- and anti-jove points [10]) would not produce the observed rotation of stress direction, unless the cracks formed in response to nonsynchronous rotation and were passively carried to their present positions by polar wandering. A minimum of 60 degrees of eastwards reorientation is required to explain the rotation inferred from the Galileo data.

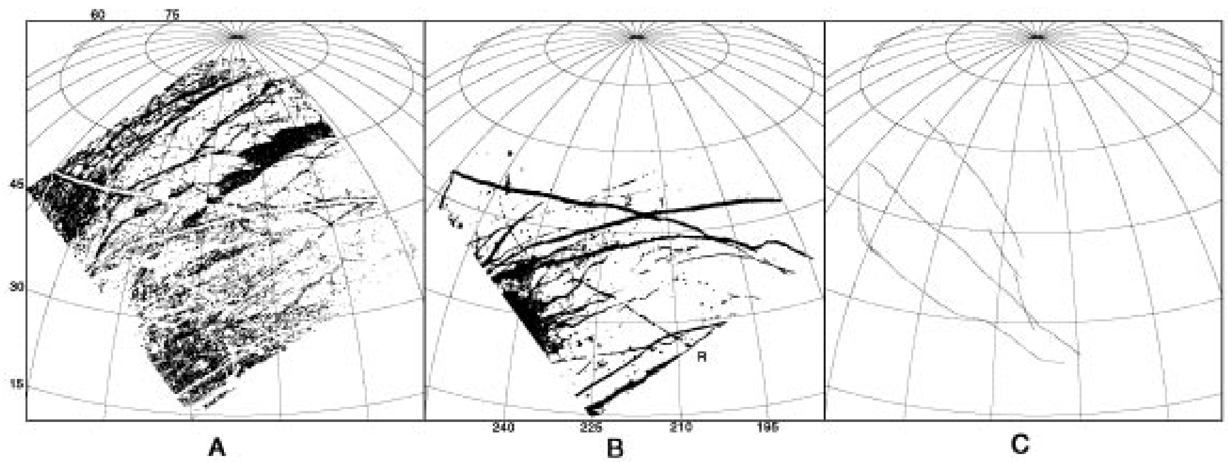

Figure 1: Distribution of ancient bands and bright wedges (A), intermediate aged triple-bands and similarly colored materials (B), and young fractures (C) which cross-cut the triple bands. In (B), 1 and 2 refer to the order of placement of the two prominent triple bands near the center of the scene, while R marks Rhadamanthys Linea, a feature evidently transitional between the young fractures and the fully developed triple-bands.

Interestingly, the orientation of the youngest fractures (incipient cracks, along with Rhadamanthys Linea) is roughly radial to the antijove point. This is not consistent with the stress pattern predicted for non-synchronous rotation, which is displaced 45 degrees to the east [7], but instead fits the current tidal stress regime. Perhaps the lineaments are produced by diurnal stresses due to Europa's forced eccentricity, and are shifted eastwards by non-synchronous rotation over much longer time scales. Extension along small circles concentric to the antijove point occurs during half of each 3.6 day orbit, as Europa recedes from Jupiter and the tidal bulges relax. Fractures radial to the antijove point may form as the ice fails in tension, perhaps incrementally over many thousands of orbits. Although the stresses are small, ice would be expected to be brittle over such short time scales, whereas it may deform plastically over the longer time scales of non-synchronous rotation. Maximum stresses due to the daily tidal flexing are reached at Europa's waist (longitudes 90 and 270) [6]; the most prominent triple bands Minos and Cadmus Linaea may have formed as their apices crossed the 270 degree meridian. Repeated opening and closing of cracks during the 3.6 day flexing cycle may be the mechanism by which dark materials associated with the triple bands (and, possibly, the icy double ridges marginal to fractures elsewhere on Europa) are "pumped" to the surface.

The interpretations suggested here are based on the small fraction of Europa's surface which has so far been imaged with sufficient spectral and spatial resolution to discern detailed superposition relationships. They should be regarded as preliminary, pending further Galileo observations. Complicating the analysis is the likelihood that fracturing of Europa's surface occurs along older pre-existing faults. Non-synchronous rotation, if it existed on Europa, does not necessarily require global subsurface oceans or decoupling of the crust from the interior, although these may be indicated if a permanent interior mass distribution asymmetry (e.g., due to subsurface topography [11]) is determined from future gravity field measurements. Outstanding questions include the mechanism and time scale for brightening of the bands, which may help constrain the rate of non-synchronous rotation and the age of geologic activity on Europa.

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